ALLIED PAPER, INC./PORTAGE CREEK/ KALAMAZOO RIVER SUPERFUND SITE

Spatial and Temporal PCB Trends in Area 1
Carp and Smallmouth Bass Fillets

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Introduction

Fish tissue samples have been collected and analyzed for total PCBs since the 1980s, with greater monitoring effort starting in 1993 at the initiation of the remedial investigation (RI). The State of Michigan and the responsible parties have collected and shared fish tissue samples on a regular basis since that time. This report discusses the spatial and temporal distribution of PCB concentration in adult Carp and adult Smallmouth Bass (SMB) as well as young of the year (YOY) SMB. This report is intended to serve as a briefing document suitable to support risk management decisions as they relate to evaluation of proposed remedial options within Area 1 of the Allied Paper, Inc./Portage Creek/Kalamazoo River Superfund Site. All results are based on standard statistical procedures that can be found in the statistical literature on linear and non-linear multiple variable regression analysis (Neter et al., 1996)

Objectives

The primary objectives of this analysis are to consider the questions that would in part determine the potential need for remedial action within the section of the Kalamazoo River from Morrow Dam downstream to the former Plainwell Dam. This area is referred to as Area 1. The focus of this analysis is on human health risks associated with exposure to PCB contamination in fish fillets. Of principal interest is to determine it fish tissue PCB concentrations are elevated beyond acceptable levels; to evaluate whether they would be expected to decline to acceptable levels naturally over a reasonable period of time; and if not to identify PCB sources (i.e. sediment and water) that could be managed to accelerate recovery over and above natural processes. The following specific questions are investigated.

- Are current PCB concentrations in Area 1 fish tissues elevated relative to consumption advisory levels?
- Are PCB concentrations in Area 1 fish tissues elevated relative to background concentrations?
- Are fish tissue PCB concentrations declining with time and if so are decay rates changing with time?
- Are PCB concentrations in fish tissue and sediment correlated?
- Are PCB concentrations in fish tissues and surface water correlated?

Methods

This report follows technical methods used by Kern Statistical Services, Inc. (2007) fitting a log-linear regression model adjusting fish tissue PCB concentrations for covariation with lipid content and fish length and estimating temporal trends and spatially driven correlations with sediment and water PCB concentrations. This statistical approach is commonly used in the health sciences when comparing endpoints that co-vary with age. For example, if one is interested in comparing cancer incidence among groups of people, it is necessary to take into account differences in the age distribution among groups, in order to accurately estimate differences in incidence rates.

PCB concentrations in fish tissue are known to vary with lipid and at times age (i.e. length is a surrogate for age) so it is necessary to adjust spatial and temporal comparisons for potential differences in the distributions of these covariates. In risk assessment, it is traditional to normalize tissue PCB levels to lipid content as an adjustment technique. The regression approach employed here provides a more flexible framework: 1) allowing adjustment for additional variables (e.g. length, age, weight); 2) accounting for the effects of these variables in statistical estimates of effects; and 3) properly accommodating the situation where the PCB-lipid relationship cannot be described by a straight line through the origin. This approach also has the distinct advantage over the more traditional approach in that confidence limits are available for all parameter estimates. Confidence limits provide necessary information about statistical uncertainty, which is frequently ignored or poorly estimated in many remedial investigation and risk assessment reports. For consistency across analyses, all analyses are lipid and length adjusted, regardless statistical significance of these relationships with tissue PCBs.

Temporal Trends

For temporal trend analysis, the general form of the log linear regression model is stated as follows:

$$\ln(\mathrm{C_{tissue}}) = \beta_0 + \beta_1 \times \mathrm{year} + \beta_2 \times \ln(\mathrm{lipid}) + \beta_3 \times \ln(\mathrm{length}) + \sum_{r=1}^{n} \alpha_r I_{Location} + \varepsilon \qquad (1)$$

where the β_i are regression coefficients associated with year, natural log of length and lipid, and α_r are coefficients representing differences in average concentration among stations. Of primary interest in this analysis, when $\beta_1$is negative, it represents the exponential decay rate with time, and $(\ln(0.5)/\beta_1)$ is an estimate of the half time (i.e. the time necessary for concentrations to decline by a factor of 2) and the anti-log of α_r (i.e. e^{α_r}) represents the ratio of geometric mean concentrations among locations. When natural log transformed concentration data are approximately normally distributed, these functions of the model parameters are maximum likelihood estimates, and their variances and confidence limits are functions of the parameter variances and confidence limits. Therefore, this multiple regression approach provides a unified framework from which parameters (and their uncertainties) important to risk management are estimated directly from the statistical model.

To test for a change in the apparent decay rate in PCB concentrations in fish tissues, a time varying decay model was also fit to the data. Exponential decay rates as are estimated in Equation 1, are based on the assumption that changes in PCB concentrations are proportional to current concentration, $dC/dt = kC$, whereas the mixed order model (Stowe et al.1999) is based on the assumption that change in concentration is proportional to a power function of concentration $dC/dt = kC^{1-\theta}$ where exponential decay is achieved for $\theta = 0$. The mixed order and exponential decay models are compared for a hypothetical data set in Figure 1. Fitting this non-linear model allows one to test the assumption of exponential decay as well as to quantify the extent to which decay rates either increase or decrease with time. Generally speaking it is thought that decay rates must slow with time as recovery processes slow and equilibrium conditions are ultimately achieved. The mixed order model was first introduced by Stowe as an alternative to the “hockey stick” for describing changing decay rates in salmonids in Lake Michigan. Thermo Retec (2001) used the “hockey stick” function to evaluate trends in PCB concentration in fish tissue at the Fox River in Green Bay Wisconsin, but this approach suffers thedisadvantage that a distinct change point (from handle to blade) must be identified from the data. Because recovery processes are continuous, this assumption of a discrete time period at which dynamics bifurcate from declining to equilibrium is not consistent with the physical situation and dynamics governing natural recovery. In 2003 Kern, used the mixed order model in evaluations of PCB decay rates in fish tissue at the Kalamazoo River, finding a more satisfying solution to the problem of determining if temporal trends are varying with time.

First Order Decay Model

$$dC / dt = kC$$

Mixed Order Time Dependent Decay

$$dC / dt = kC^{1-\theta}$$

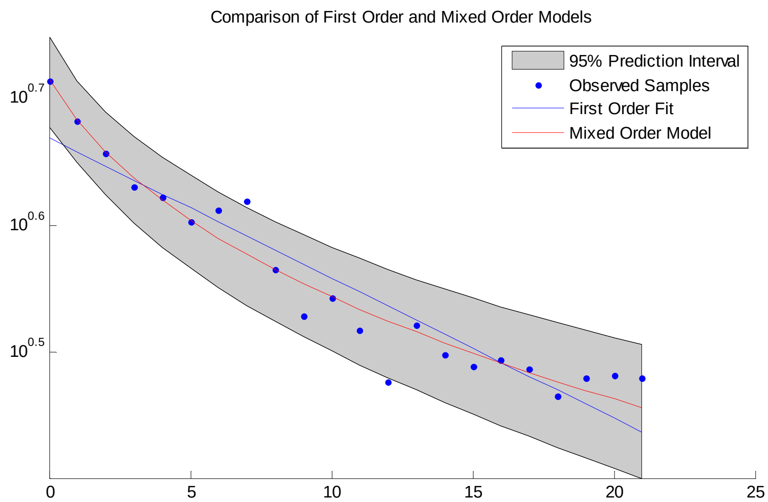

Figure 1. Comparison of mixed order model and first order decay fit to data that is decaying more slowly than exponential decay.

PCB Accumulation from Sediment and Water Exposures

Active management of risks associated with PCB contamination in fish tissues requires an understanding of the critical exposure pathways for fish, and an understanding of the rate at which fish tissue concentrations might be expected to change per unit change in bed sediment or water column PCB concentrations. These relationships have traditionally be summarized through development of biota to sediment or biota to water accumulation factors which are based on the assumption that on a lipid and organic carbon content basis PCB concentration in tissue is directly proportional to PCB concentration in sediment and water. In practice, these accumulation factors often vary with sediment or water concentrations leading to difficulty establishing consistent predictable relationships. Kern and Field found that at the Hudson River, apparently spatially varying BSAFs could be explained by noting that PCB concentrations were non-linearly related to sediment PCB concentrations, with greater accumulation factors at lower sediment PCB concentrations. Through a regression analysis, they found that fish tissue concentrations were proportional to approximately the square root of sediment PCB levels. In this report, similar methods were applied to data from the Kalamazoo River in efforts to develop a consistent relationship between tissue and sediment PCB concentrations. A modification to Equation 1 provides a regression model that was used to develop this relationship for Carp and SMB fillets at the Kalamazoo River.

$$\ln(\mathrm{C_{tissue}}) = \beta_0 + \beta_1 \times \ln(\mathrm{lipid}) + \beta_2 \times \ln(\mathrm{length}) + \beta_3 \times \ln(\mathrm{C}_{sediment}) + \beta_4 \times \ln(\mathrm{TOC}) + \varepsilon \qquad (2)$$

It is important to note that the usual BSAF used to relate tissue and sediment PCB concentrations is a special case of this regression model. The BSAF relationship is obtained when $\beta_1 = \beta_3 = -\beta_4 = 1.0$ and $\beta_2 = 0$. This relationship provides a means to test the hypothesis that PCB concentrations in fish tissue are linearly related to PCB concentrations in sediment. Similar models can be obtained for water by replacing the sediment term with a water concentration term, or both water and sediment source terms can be included and tested to determine if one or the other or both are integral in explaining spatial variation in fish tissue PCB concentrations. In this analysis, models with and without water and sediment terms were compared using adjusted R^2 to determine the most parsimonious set of explanatory variables for describing the spatial distribution of PCB concentration in fish tissue levels. Because Carp and SMB are generally wide ranging species, water and sediment concentrations were obtained by averaging sample data within the approximate extent of each ABSA. This is equivalent to assuming that over their life span, and over the range of areas within which they were captured, these fish were exposed to the range of sediment and water conditions represented by the sediment samples within the ABSA where they were captured. Effectively each fish tissue concentration was paired with the average sediment and water PCB concentrations and TOC content for the ABSA within which it was captured.

Variations on the regression models above, with modifications to incorporate specific terms to answer each question--time, location or sediment as predictors, were used to evaluate the following questions:

- Are PCB levels elevated in current fish tissues?
- Do temporal trends from 1993 to present indicate that tissue levels will reach "background" or risk based levels (i.e., 0.05 mg/kg for unlimited consumption, or 0.2 mg/kg for consumption of one meal per week) soon?
- How much would tissue exposures need to be reduced to reach "background" or consumption advisory levels (i.e., 0.05 mg/kg or 0.2 mg/kg).
- How long would it take for tissue PCB levels to reach consumption advisory levels.
- Are fish tissue PCB concentrations associated with sediment PCB concentrations –which would suggest that reduced sediment or water concentrations could reduce tissue PCB levels?

Findings

The temporal and spatial distribution of fillet samples in reference areas, locations within Area 1, and Lake Allegan and New Richmond (areas downstream of Area 1) are summarized in Table 1. Common Carp (Carp) and Smallmouth Bass (SMB) have received the greatest attention in most years, although a broader range of species were targeted in 2009. It can also be seen that the number of locations (ABSAs) increased in 1993 with the initiation of remedial investigations. It can also be seen that the number of samples per year and the number of years sampled since 1993 provide adequate numbers samples to support trend estimates for Carp and Smallmouth

Bass at Battle Creek, Morrow Pond, Kalamazoo Avenue, Plainwell Impoundment, Lake Allegan and New Richmond.

Recent PCB Concentrations

The regression model described above was used to compare current conditions (i.e., from 2006 through 2009) in Area 1 ABSAs and in Lake Allegan to advisory levels and background/reference conditions in Battle Creek and Morrow Lake. All fish tissue concentrations were length and lipid adjusted to allow for consistent comparisons under circumstances where average lipid and length distribution may vary among years or ABSAs or both. The regression adjustments provide the statistical equivalent to a controlled sample of fish with evenly distributed sizes and lipid content among locations and time steps.

Table 1. Spatial and temporal distribution of fish fillet sampling effort at the Kalamazoo River Superfund Site.

Species Group	Sampling Area	1983	1985	1986	1987	1990	1991	1992	1993	1994	1997	1999	2000	2001	2006	2009	Grand Total
BLACK CRAPPIE	LAKE ALLEGAN											1	1				2
BLACK CRAPPIE Total												1	1				2
BULLHEAD	D AVENUE															11	11
BULLHEAD Total																11	11
CARP	BATTLE CREEK				9		5		11		11	11	11	11	11		80
	MORROW LAKE		20	20	9				11		11	22		11	11	11	126
	KALAMAZOO AVENUE	11	18	20					11			11	6		11		88
	D AVENUE												5			22	27
	PLAINWELL DAM NO 2															11	11
	PLAINWELL IMPOUNDMENT	11	20	21	9				11		11	22		11	11	11	138
	LAKE ALLEGAN	3	19	81	10	10		9	11	10	11	22	11	11	11	11	230
	DOWNSTREAM OF ALLEGAN DAM								11								11
	NEW RICHMOND								11		12	21		11	11		66
CARP Total		25	77	142	37	10	5	9	77	10	56	109	33	55	66	66	777
CATFISH	MORROW LAKE													1			1
	LAKE ALLEGAN											12		6	11	11	40
	NEW RICHMOND											2		4	3		9
CATFISH Total												14		11	14	11	50
LARGEMOUTH BASS	BATTLE CREEK				1												1
	MORROW LAKE		3														3
	LAKE ALLEGAN	2	7										1				10
	NEW RICHMOND											1					1
LARGEMOUTH BASS Total		2	10		1							1	1				15
PERCH	LAKE ALLEGAN											11	2				13
	NEW RICHMOND											11					11
PERCH Total												22	2				24

Table 1. Spatial and temporal distribution of fish fillet sampling effort at the Kalamazoo River Superfund Site.

Species Group	Sampling Area	1983	1985	1986	1987	1990	1991	1992	1993	1994	1997	1999	2000	2001	2006	2009	Grand Total
NORTHERN PIKE	KALAMAZOO AVENUE												1				1
	LAKE ALLEGAN				3							11					14
	NEW RICHMOND											4					4
NORTHERN PIKE Total					3							15	1				19
SMALLMOUTH BASS	BATTLE CREEK				1		4		11		11	11	11	11	11		71
	MORROW LAKE		4		10				11		11	22		11	11	11	91
	KALAMAZOO AVENUE		2						11			11	11	1	11		47
	D AVENUE												11			22	33
	PLAINWELL DAM NO 2															11	11
	PLAINWELL IMPOUNDMENT		1						11		11	22		11	11	11	78
	LAKE ALLEGAN		3		10				11		11	21	10	11	11	11	99
	DOWNSTREAM OF ALLEGAN DAM								11								11
	NEW RICHMOND								11		11	19		10	11		62
SMALLMOUTH BASS Total			10		21		4		77		55	106	43	55	66	66	503
SUNFISH	KALAMAZOO AVENUE											11	1				12
	D AVENUE															22	22
	LAKE ALLEGAN	1										11				22	34
SUNFISH Total		1										22	1			44	68
Grand Total		28	97	142	62	10	9	9	154	10	111	290	82	121	146	198	1469

Figure 2 and Table 2 show recent (2006-2009) adjusted total PCB concentrations in carp fillets exceed the 0.05 mg/kg unlimited consumption advisory by a factor of 20 to 50. Carp fillet PCBs exceed the 0.2 mg/kg one meal per week advisory level by approximately one order of magnitude. Carp fillet PCB concentrations exceed the no consumption level at all locations, including Battle Creek, the least industrialized reference area. The highest adjusted PCB concentrations in carp fillets occur at Lake Allegan.

Figures 2 and 3 show that PCB concentrations in both Carp and Smallmouth Bass fillets increase with distance down-stream, with relatively larger step increase in Carp PCB concentrations near Kalamazoo Avenue whereas Smallmouth Bass PCB concentrations tend to increase more gradually from Kalamazoo Avenue to Plainwell and finally Lake Allegan.

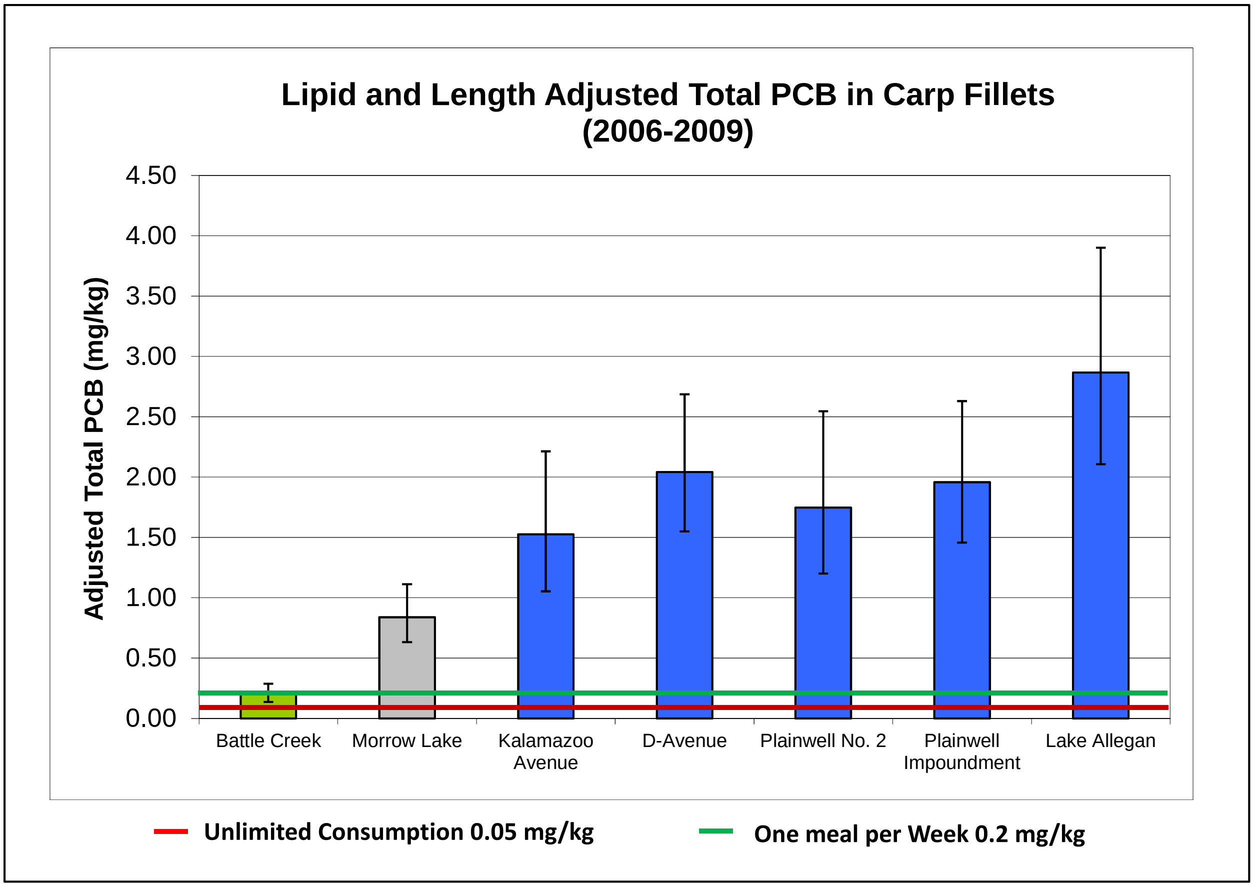

Figure 2. Lipid and length adjusted total PCB concentration in Carp fillets (2006-2009).

Table 2. Lipid and length adjusted geometric mean PCB concentrations in carp fillets at the Kalamazoo river Superfund Site for all samples collected in 2006 and 2009 at selected ABSAs.			
	Adjusted Total PCB (mg/kg)		
ABSA	Geometric Mean	LCL 95	UCL 95
Battle Creek	0.20	0.14	0.29
Morrow Lake	0.84	0.63	1.11
Kalamazoo Avenue	1.53	1.05	2.21
D-Avenue	2.04	1.55	2.69
Plainwell No. 2	1.75	1.20	2.54
Plainwell Impoundment	1.96	1.46	2.63
Lake Allegan	2.87	2.11	3.90

To compare carp fillet concentrations within Area 1 and Lake Allegan to background or reference concentrations, the ratios of adjusted geometric mean PCB levels in carp fillets between downstream or "site" locations and Battle Creek and Morrow Pond (reference locations) were calculated (Table 4 and Figure 4). The upper panels show comparisons for Carp fillet PCB concentrations and the lower panels provide ratios for Smallmouth Bass. The Left panels in Figure 4 show the ratios between Area 1 ABSAs and Battle Creek, whereas he Right hand panels provide ratios between Area 1 ABSAs and Morrow Pond.

PCB concentrations in Area 1 Carp fillets exceed those at Battle Creek by a factor of 6 to 10 and they exceed Morrow Pond by a factor of approximately 2 to 3. Figure 4 also shows that Smallmouth Bass fillet concentrations exceed those at Battle Creek by a factor of 6 to 26. Within Area 1, Smallmouth Bass fillet concentrations at Kalamazoo Avenue and Avenue D are similar to those at Morrow Pond. Concentrations in Smallmouth Bass Fillets at Plain well No.2 and Plainwell Impoundment exceeded those at Morrow Pond by a factor of approximately 1.5 and 3.5 respectively.

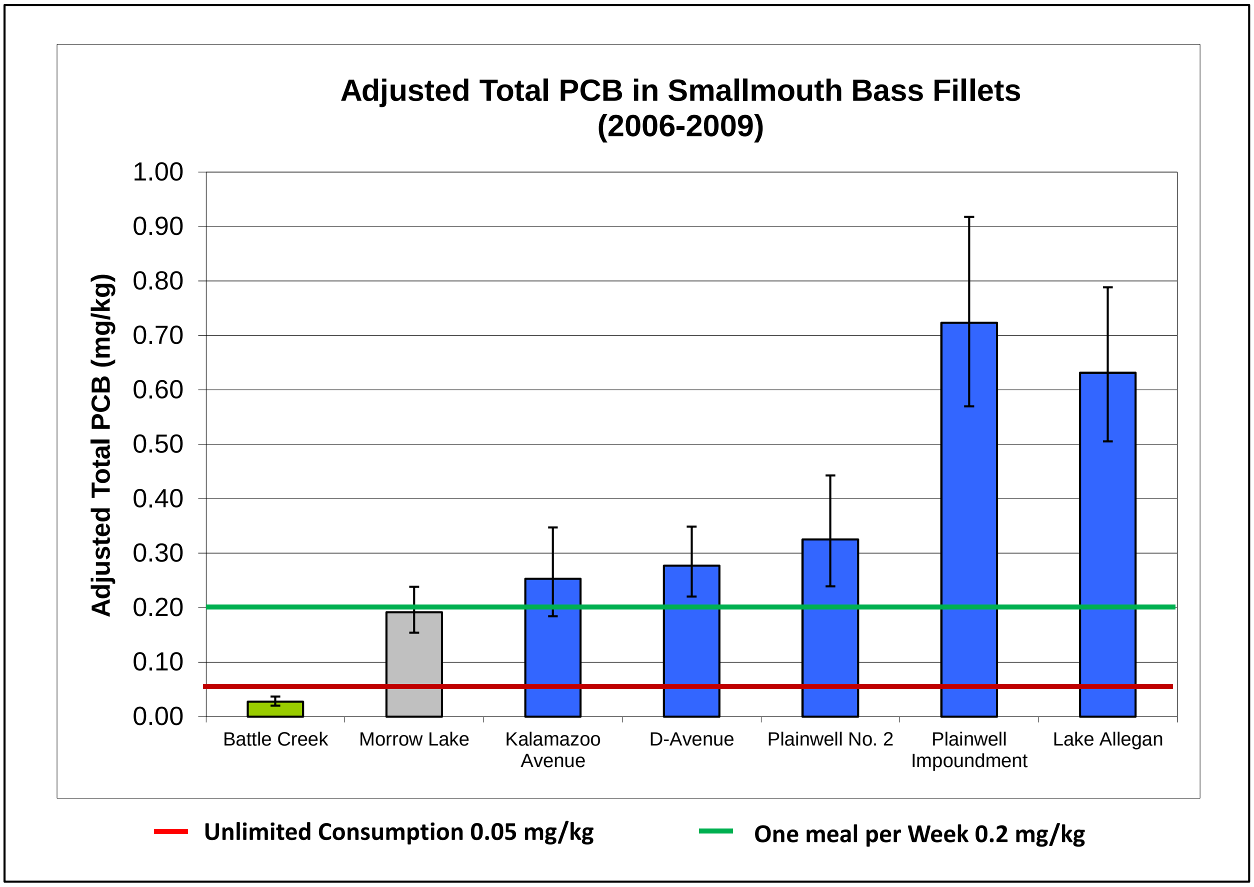

Figure 3. Lipid and length adjusted total PCB concentration in Carp fillets (2006-2009).

Table 3. Lipid and length adjusted geometric mean PCB concentrations in smallmouth bass fillets at the Kalamazoo River Superfund Site for all samples collected in 2006 and 2009.

	Total PCB (mg/kg)		
ABSA	Geometric Mean	LCL 95	UCL 95
Battle Creek	0.03	0.02	0.04
Morrow Lake	0.19	0.15	0.24
Kalamazoo Avenue	0.25	0.18	0.35
D-Avenue	0.28	0.22	0.35
Plainwell No. 2	0.33	0.24	0.44
Plainwell Impoundment	0.72	0.57	0.92
Lake Allegan	0.63	0.51	0.79

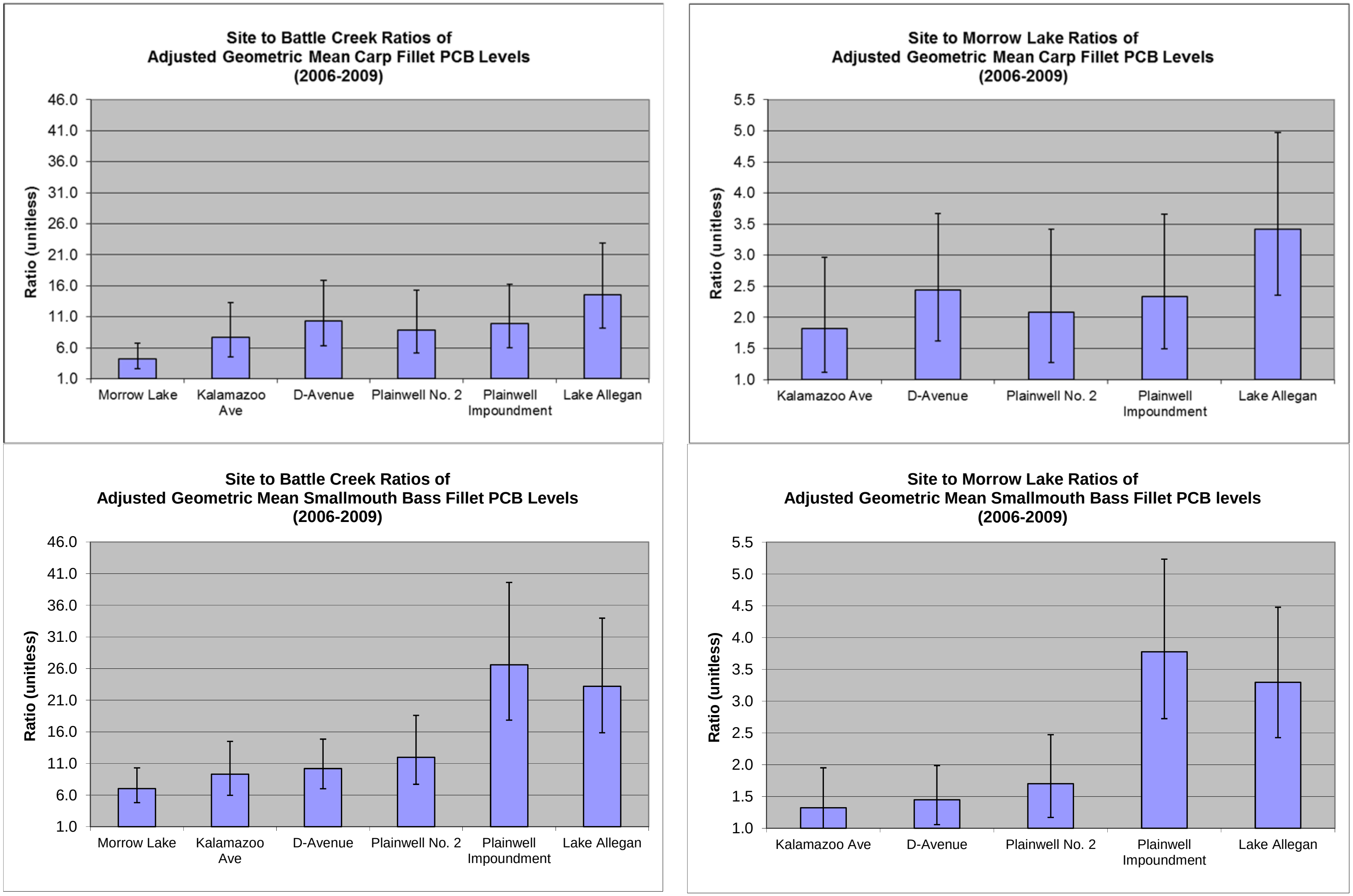

Figure 4. Ratios of Adjusted Geometric Mean PCB Levels in Recently Collected Carp Fillets (upper panels) and Smallmouth Bass Fillets (lower panels). Left and right panels illustrate the ratios between site levels and levels in Battle Creek and Morrow Lake respectively.

Table 4. Ratio of adjusted geometric mean fillet PCB concentrations in carp fillets from site ABSAs to those from upstream of the site.

				95% Confidence Limits for Ratios	
	Denominator	Numerator	Ratio of Geometric Means	Lower Limit	Upper Limit
Carp	Battle Creek	Morrow Lake	4.2	2.7	6.7
		Kalamazoo Ave	7.7	4.5	13.3
		D-Avenue	10.3	6.3	16.8
		Plainwell No. 2	8.8	5.1	15.2
		Plainwell Impoundment	9.9	6.0	16.3
		Lake Allegan	14.5	9.2	22.9
	Morrow Lake	Kalamazoo Ave	1.8	1.1	3.0
		D-Avenue	2.4	1.6	3.7
		Plainwell No. 2	2.1	1.3	3.4
		Plainwell Impoundment	2.3	1.5	3.7
		Lake Allegan	3.4	2.4	5.0
Smallmouth Bass	Battle Creek	Morrow Lake	7.0	4.8	10.3
		Kalamazoo Ave	9.3	6.0	14.5
		D-Avenue	10.2	7.0	14.8
		Plainwell No. 2	12.0	7.7	18.6
		Plainwell Impoundment	26.6	17.9	39.6
		Lake Allegan	23.2	15.9	34.0
	Morrow Lake	Kalamazoo Ave	1.3	0.9	2.0
		D-Avenue	1.4	1.1	2.0
		Plainwell No. 2	1.7	1.2	2.5
		Plainwell Impoundment	3.8	2.7	5.2
		Lake Allegan	3.3	2.4	4.5

Table 5 and Figure 5 provide the adjusted total PCB concentrations in whole-body YOY smallmouth bass by location. Concentrations in Area 1 ABSAs, Lake Allegan, and New Richmond are well above reference level concentrations represented by Battle Creek. Concentrations range from roughly 10 times Battle Creek tissue concentrations at Kalamazoo Avenue to approximately 15 times reference concentrations at Plainwell Impoundment. PCB concentrations in YOY Smallmouth Bass at Kalamazoo Avenue were approximately double those at Morrow Pond, and those at Plainwell were approximately a factor of three times higher.

Table 5. Lipid and length adjusted geometric mean PCB concentrations in smallmouth bass YOY (whole body) fillets at the Kalamazoo river Superfund Site for all samples collected in 2006 and 2009.

	Total PCB (mg/kg)		
ABSA	Geometric Mean	LCL 95	UCL 95
Battle Creek	0.12	0.11	0.14
Morrow Lake	0.45	0.38	0.54
Kalamazoo Avenue	1.00	0.88	1.13
D-Avenue	1.06	0.95	1.19
Plainwell No. 2	1.28	1.13	1.45
Plainwell Impoundment	1.50	1.37	1.63
Lake Allegan	1.11	0.98	1.26
New Richmond	0.71	0.62	0.81

Area 1 concentrations of PCB levels in smallmouth bass YOY (whole body) were statistically compared to reference concentrations at Battle Creek (Table 6 and Figure 6, left panel) and concentrations in Morrow Lake (Table 6 and Figure 6, right panel) using ratios of adjusted geometric mean PCB levels between site locations and Battle Creek and Morrow Lake, respectively. Concentrations at all locations (including Morrow Lake) are significantly greater than reference concentrations at Battle Creek. Concentrations at all site locations downstream of Morrow Lake are also significantly greater than concentrations at Morrow Lake.

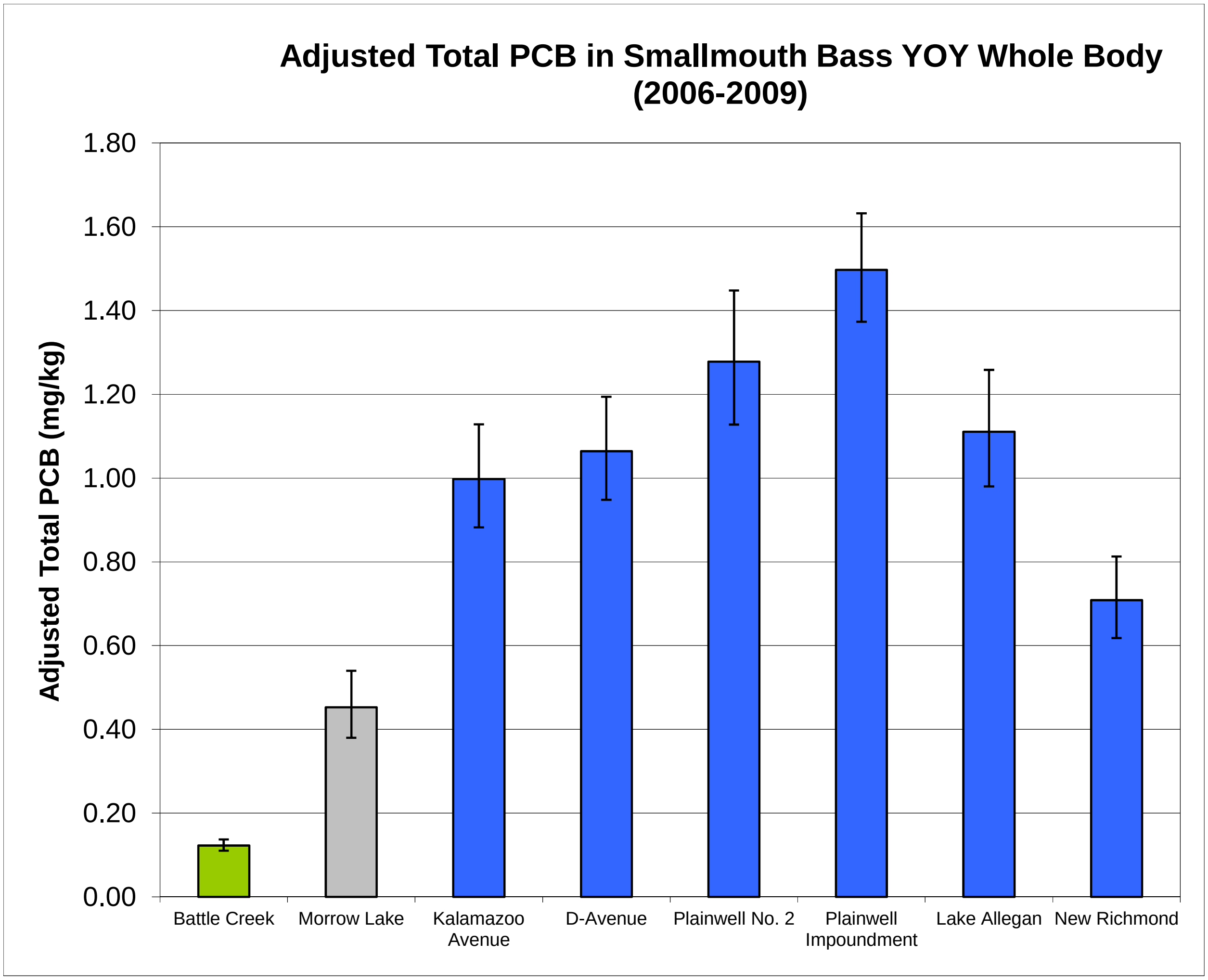

Figure 5. Adjusted Total PCB Levels in Recently Collected Smallmouth Bass (Young of Year Whole Body).

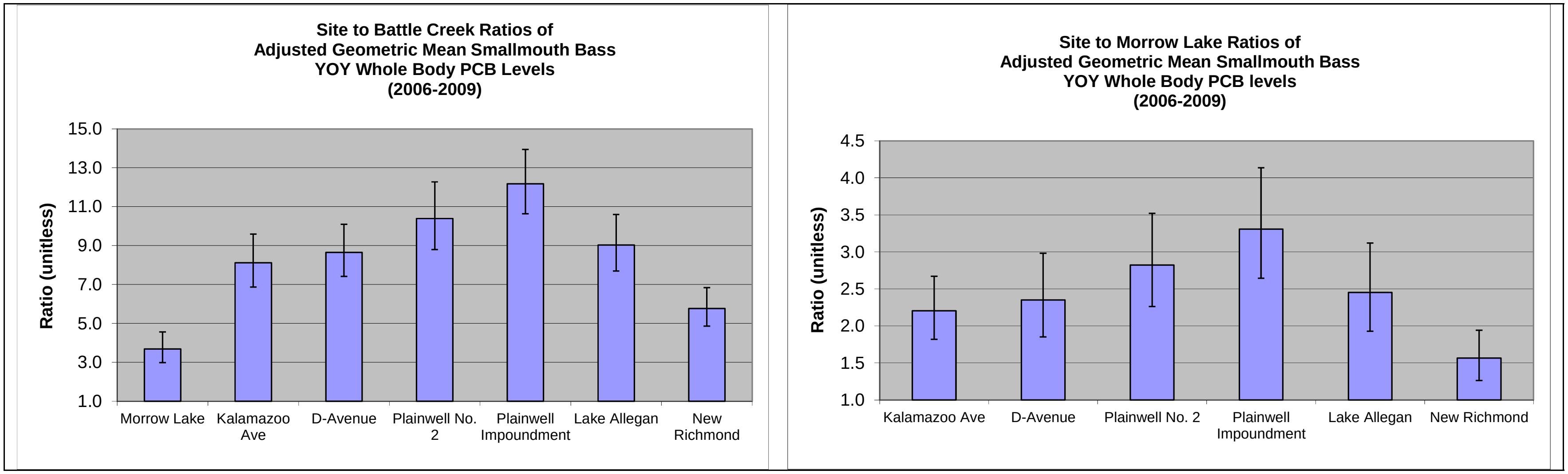

Figure 6. Ratios of Adjusted Geometric Mean PCB Levels in Recently Collected Smallmouth Bass Young of the Year Whole Body. The panels illustrate the ratios between site levels and levels in Battle Creek (left panel) and Morrow Lake (right panel).

Table 6. Ratio of adjusted geometric mean fillet PCB concentrations in smallmouth bass YOY (whole body) from site ABSAs to those from upstream of the site.				
			95% Confidence Limits for Ratios	
Denominator	Numerator	Ratios of Geometric Means	Lower Limit	Upper Limit
Battle Creek	Morrow Lake	3.7	3.0	4.6
	Kalamazoo Ave	8.1	6.9	9.6
	D-Avenue	8.7	7.4	10.1
	Plainwell No. 2	10.4	8.8	12.3
	Plainwell Impoundment	12.2	10.6	13.9
	Lake Allegan	9.0	7.7	10.6
	New Richmond	5.8	4.9	6.8
Morrow Lake	Kalamazoo Ave	2.2	1.8	2.7
	D-Avenue	2.3	1.9	3.0
	Plainwell No. 2	2.8	2.3	3.5
	Plainwell Impoundment	3.3	2.6	4.1
	Lake Allegan	2.5	1.9	3.1
	New Richmond	1.6	1.3	1.9

Temporal Trends in PCB Concentrations

Temporal trends in total adjusted PCB concentrations in fish tissue were evaluated using tissue samples collected from 1993 to present. Estimates of PCB half times were generated by dividing the regression coefficient for the time term (YEAR) into the natural log of 0.5 (i.e., ln(0.5)), as shown in Table 7. In general, natural recovery is slow, and varies with species and locations. Half time estimates generally range between 10 and 30 years.

A statistically significant downward trend could not be demonstrated in adult smallmouth bass fillets in Morrow Lake and Lake Allegan, YOY smallmouth bass fillets in Battle Creek and Morrow Lake, and adult carp fillets in Battle Creek, indicating that at best recovery is slow and at worst, equilibrium conditions may have been achieved. The 95 percent lower confidence limits for the half-time were quantifiable at all locations and generally range from 4 to 37 years, with a half time of 990 in YOY smallmouth bass fillets in Morrow Lake. The quantified 95 percent upper confidence limits for half times range from 16 through 408 years, with almost half of ABSAs failing to show declining PCB concentrations.

Current concentrations, and estimated half times were used to calculate the number of years that would be required for tissue PCB concentrations in fillets to reach the 0.2 mg/kg one meal per week advisory level and the 0.05 mg/kg unlimited consumption level. Additionally, the time for whole body YOY SMB to reach 0.5mg/kg and 0.6 mg/kg risk based thresholds for mink. These calculations resulted in approximate 95% confidence limits for the time necessary for central tendency PCB concentrations (i.e. geometric mean) threshold levels. Table 9 shows that for Carp in Area 1, the Lower 95% confidence limit on the time to 0.2 mg/kg can be expected to range from 20 to 30 years in Area 1. For Smallmouth Bass, the time to reach 0.2 mg/kg would be as little as three years at Kalamazoo Avenue but over 20 years at Plainwell Impoundment.

Table 8. Summary of Half Time Estimates for Carp and Smallmouth Bass					
			Half Time Estimates		
Age Group	ABSA	Species	Half Time	LCL 95	UCL 95
Adult	Battle Creek	Carp	Not Declining	22	Not Declining
		Smallmouth Bass	20	11	103
	Morrow Lake	Carp	27	12	Not Declining
		Smallmouth Bass	Not Declining	37	Not Declining
	Kalamazoo Ave	Carp	11	8	17
		Smallmouth Bass	14	8	39
	Plainwell Dam	Carp	16	12	28
		Smallmouth Bass	28	14	408
	Lake Allegan	Carp	15	9	85
		Smallmouth Bass	Not Declining	45	Not Declining
YOY	Battle Creek	Smallmouth Bass	Not Declining	25	Not Declining
	Morrow Lake	Smallmouth Bass	Not Declining	990	Not Declining
	Kalamazoo Ave	Smallmouth Bass	24	5	Not Declining
	Plainwell Dam	Smallmouth Bass	17	12	32
	Lake Allegan	Smallmouth Bass	7	4	16

Table 9. Summary of Half Time Estimates and Times to Threshold Concentration Levels for Carp and Smallmouth Bass									
				Time to Threshold Levels (0.2 mg/kg Fillet or 0.6 mg/kg Whole Body)			Time to Threshold Levels (0.05 mg/kg Fillet or 0.5 mg/kg Whole Body)		
Age Group	ABSA	Species	Recent Concentration (2006-2009)	Time to Threshold[1]	LCL 95	UCL 95	Time to Threshold[1]	LCL 95	UCL 95
Adult	Battle Creek	Carp	0.20	Currently at or Below 0.2	Currently at or Below 0.2	Currently at or Below 0.2	Not Declining	44	Not Declining
		Smallmouth Bass	0.03	Currently at or Below 0.2	Currently at or Below 0.2	Currently at or Below 0.2	Currently at or Below 0.05	Currently at or Below 0.05	Currently at or Below 0.05
	Morrow Lake	Carp	0.84	55	25	Not Declining	108	49	Not Declining
		Smallmouth Bass	0.19	Currently at or Below 0.2	Currently at or Below 0.2	Currently at or Below 0.2	Not Declining	71	Not Declining
	Kalamazoo Ave	Carp	1.53	31	22	50	52	37	84
		Smallmouth Bass	0.25	4	3	13	32	20	91
	Plainwell Dam	Carp	1.96	54	38	91	87	62	146
		Smallmouth Bass	0.72	51	26	753	106	55	1569
	Lake Allegan	Carp	2.87	59	33	325	90	50	494
		Smallmouth Bass	0.63	Not Declining	15	Not Declining	Not Declining	27	Not Declining

Table 9. Summary of Half Time Estimates and Times to Threshold Concentration Levels for Carp and Smallmouth Bass									
				Time to Threshold Levels (0.2 mg/kg Fillet or 0.6 mg/kg Whole Body)			Time to Threshold Levels (0.05 mg/kg Fillet or 0.5 mg/kg Whole Body)		
Age Group	ABSA	Species	Recent Concentration (2006-2009)	Time to Threshold[1]	LCL 95	UCL 95	Time to Threshold[1]	LCL 95	UCL 95
YOY	Battle Creek	Smallmouth Bass	0.12	Currently at or Below 0.6	Currently at or Below 0.6	Currently at or Below 0.6	Currently at or Below 0.5	Currently at or Below 0.5	Currently at or Below 0.5
	Morrow Lake	Smallmouth Bass	0.45	Currently at or Below 0.6	Currently at or Below 0.6	Currently at or Below 0.6	Currently at or Below 0.5	Currently at or Below 0.5	Currently at or Below 0.5
	Kalamazoo Ave	Smallmouth Bass	1.00	18	3	Not Declining	24	5	Not Declining
	Plainwell Dam	Smallmouth Bass	1.50	23	15	42	27	19	50
	Lake Allegan	Smallmouth Bass	1.11	6	4	14	8	5	18

Varying Decay Rates

To evaluate the variability in decay rates over time, mixed order models were used to estimate time dependent decay rates (Figures 7). In most cases, a declining rate of decay over time is evident by the concave up shape when plotted in natural log scale. Exponential decay functions are linear when plotted on log-scale vertical axes. It can also be seen that the difference between exponential decay (i.e. a straight line fit) and the fitted mixed order model is not great, relative to the large spread in PCB concentrations among individual fish captured in any given year—on the order of aa full order of magnitude. This should not be construed as a poor model, but rather an indication of the natural variation in PCB concentrations that is seen among individual fish.

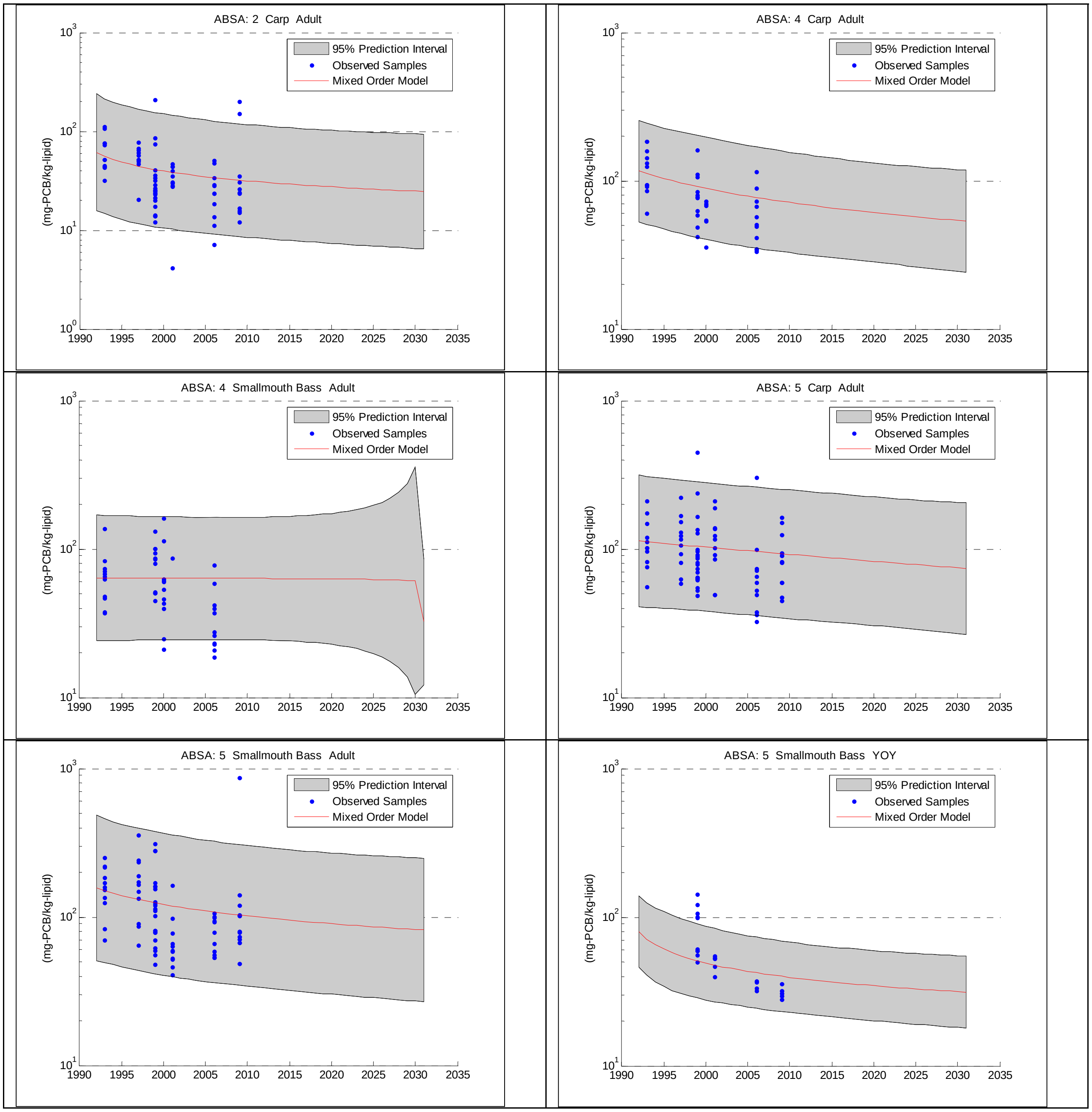

Figure 7. Mixed order model fit to fillets from adult Carp and Smallmouth Bass, and YOY Smallmouth Bass.

Association between tissue and sediment PCB concentrations

The regression approach was also used to estimate a non-linear relationship between tissue and sediment PCB concentrations. Sediment PCB concentrations were statistically significant predictors of fish tissue PCB concentrations for both Carp and Smallmouth Bass.

Estimated regression coefficients and standard errors are provided in Table 8 for both Carp and Smallmouth Bass.For both species the hypothesis that tissue concentraions would be linear in sediment concentrations was rejected in favor of an approximately square root relationship. This non-linearity in the accumulation rate was due to a smaller ratio for fish captured in areas with higher sediment PCB concentrations. The coefficient for sediment was approximately 0.5 representing an approximate square root relationship. Figure 8 shows observed PCB concentrations plotted against predicted values, illustrating the approximately 70% adjusted R^2 for the carp model and 57% adjusted R^2 for the Smallmouth Bass Model.

The contribution of water PCB concentration to prediction of fish tissue PCB concentration was also tested and it was found that for Carp, addition of water provided little improvement in model fit, whereas for Smallmouth Bass model fit was somewhat better with the inclusion of water, suggesting that Carp and Smallmouth Bass may have somewhat different exposure pathways, with the water component reflecting the higher trophic level of Smallmouth Bass than Carp. It is also important to note that water and sediment concentrations exhibit similar patterns of spatial variability, limiting the potential to differentiate water and sediment sources from the available data and sampling design.

Table 10. Tissue to sediment relationship for Carp and Smallmouth Bass Fillets at the Kalamazoo River.

Species	Model Terms	Parameter Estimate	Std. Error	t value	Pr(>|t|)
Carp	(Intercept)	1.809	0.905	2	0.046
	log(fat)	0.785	0.032	24.25	0.000
	log(Length)	-0.181	0.208	-0.87	0.384
	log(AvgPCB_mgkg) Sediment	**0.566**	0.021	27.34	0.000
	log(AvgTOC_mgkg) Sediment	-0.141	0.040	-3.54	0.000
		Adjusted R-squared:			**0.69**
Smallmouth Bass	(Intercept)	1.5134	0.6877	2.201	0.0280
	log(fat)	0.642	0.043	14.89	2.00E-16
	log(Length)	0.588	0.167	3.53	0.000447
	log(AvgPCB_mgkg) Sediment	**0.552**	0.021	26.77	2.00E-16
	log(AvgTOC_mgkg) Sediment	0.456	0.082	5.58	3.46E-08
		Adjusted R-squared:			**0.57**

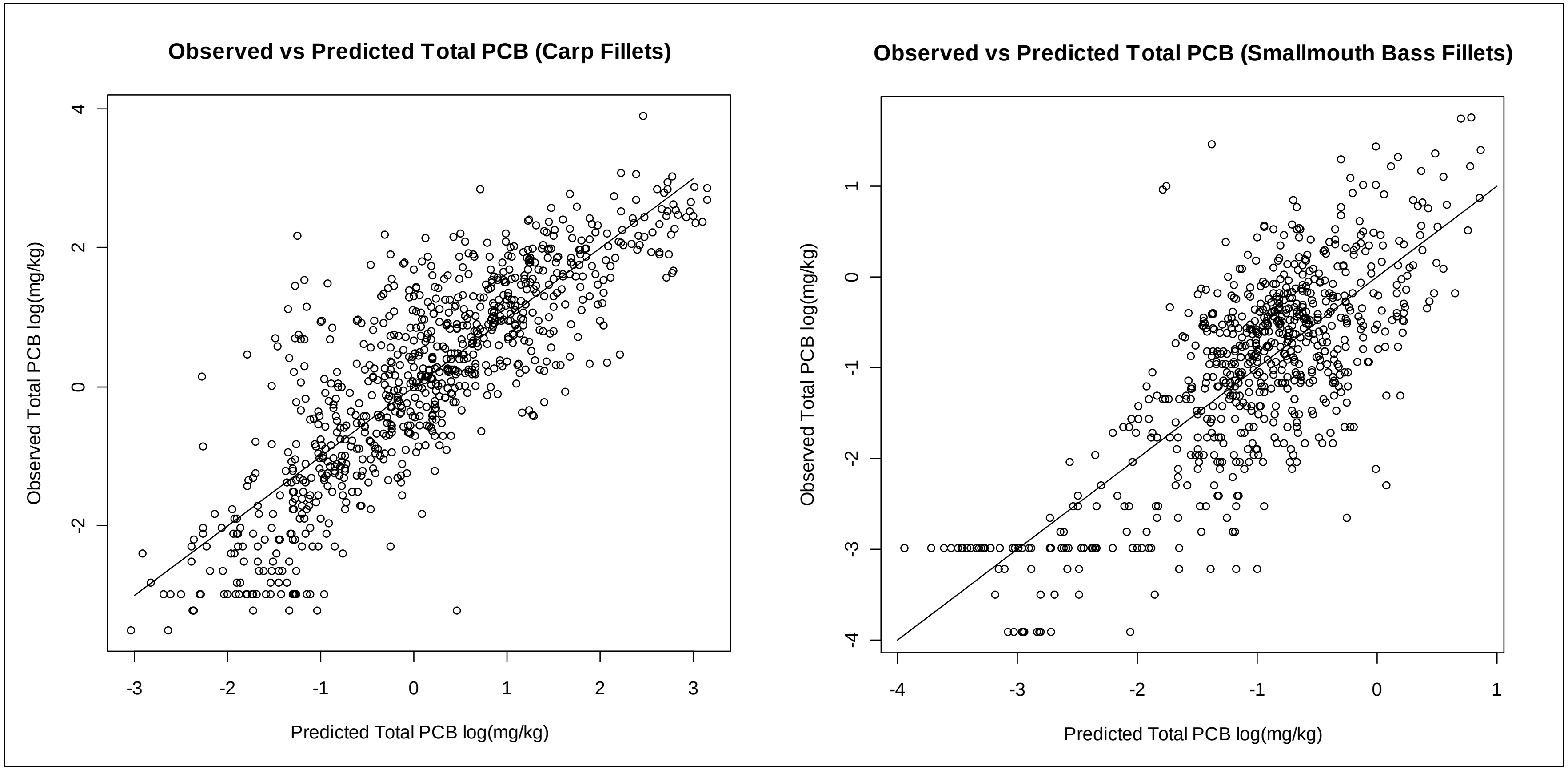

Figure 8. Observed vs. predicted total PCB concentration in Carp and Smallmouth Bass fillets: Kalamazoo River and Portage creek.

Table 11. Adjusted R-Squared for tissue PCB regression models based on sediment and water column PCB concentrations		
	SMB	Carp
Sediment	57%	**69%**
Water	53%	64%
Sediment +Water	**61%**	70%

Summary

PCB concentrations in Smallmouth Bass and Carp fillets within Area 1 are expected to be important drivers of risk management decisions for instream sediments in Area 1. These analyses have shown that

1) Carp and Smallmouth Bass tissue PCB concentrations remain elevated above consumption advisory levels as well as tissue levels from upstream reference areas.
2) Natural recovery is slow at best with relatively long half times that translate into recovery times measured in Decades for Carp, but much shorter time horizons for Smallmouth Bass.
3) Tissue PCB levels in both species were demonstrated to be associated with both sediment and water PCB levels, with stronger associations with sediment than water, suggesting that remediation of sediments would be expected to accelerate declining PCB concentrations.
4) Expected time to 0.2 mg/kg levels for Smallmouth Bass is anticipated to be relatively short, on the order of a decade or less, at the upstream end of Area 1 (i.e near and presumably upstream of Kalamazoo Avenue).
5) Time to reach 0.2 mg/kg threshold for carp is expected to range from 30 to 50 years in Area 1. The time to reach the 0.05 mg/kg would be longer, requiring an additional 2 half times to decline from 0.2 to 0.05.
6) The effectiveness of the TCRA is not currently known, but absent the removal action natural reduction of both Carp and Smallmouth Bass PCB concentrations were anticipated to take at 2 to 3 decades to achieve levels that might trigger modification of fish advisories.

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